Development of Flow Boiling and Condensation Experiment on the International Space Station- Normal and Low Gravity Flow Boiling Experiment Development and Test Results

Henry K. Nahra*, Nancy Hall*, Mojib Hasan*, James Wagner*, Rochelle May*, Jeffrey Mackey*, John Kolacz*, Robert Butcher*, Bruce Frankenfield*

Issam Mudawar**, Chris Konichi**, Hyounsoon Lee**

*NASA-GRC; ** Purdue University

29th American Society for Gravitational and Space Research
November 3 – 8, 2013
Orlando, Florida, USA

AGENDA

- ISS Flight Experiment Objective
- Fluid System-ISS
- Test Modules
  - Flow Boiling Module
  - Condensation Module – Flow Visualization
  - Condensation Module – Heat Transfer
- Ground Testing
  - Breadboard Development
  - Pre-Heater Characterization
  - Proposed On-Orbit Degassing System Testing
- Flow Boiling Module Performance Assessment-Zero-G Testing
  - Fluid system
  - Diagnostics and Data Acquisition
  - FBM Heater control
- Sample of Testing Results
  - FBM Two Heaters
- Future Work

ISS Flight Experiment

FBCE Science Objectives

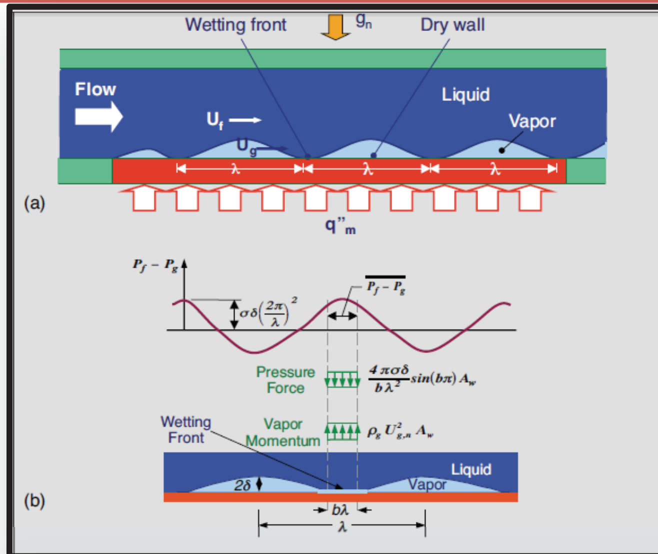
The proposed research aims to develop an **integrated two-phase flow boiling/condensation facility for the International Space Station (ISS)** to serve as primary platform for obtaining two-phase flow and heat transfer data in microgravity.

Key objectives are:

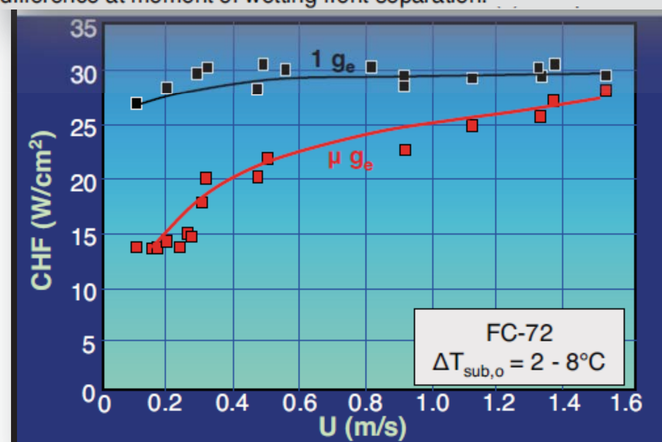
1. Obtain **flow boiling database** in long-duration microgravity environment
2. Obtain **flow condensation database** in long-duration microgravity environment
3. Develop experimentally validated, **mechanistic model** for microgravity flow boiling **critical heat flux (CHF)** and **dimensionless criteria** to predict **minimum flow velocity** required to ensure **gravity-independent CHF**
4. Develop experimentally validated, **mechanistic model** for microgravity annular condensation and **dimensionless criteria** to predict **minimum flow velocity** required to ensure **gravity-independent annular condensation**; also develop correlations for other condensation regimes in microgravity

Applications include:

1. Rankine Cycle Power Conversion System for Space
2. Two Phase Flow Thermal Control Systems and Advanced Life Support Systems
3. Gravity Insensitive Vapor Compression Heat Pump for Future Space Vehicles and Planetary Bases
4. Cryogenic Liquid Storage and Transfer

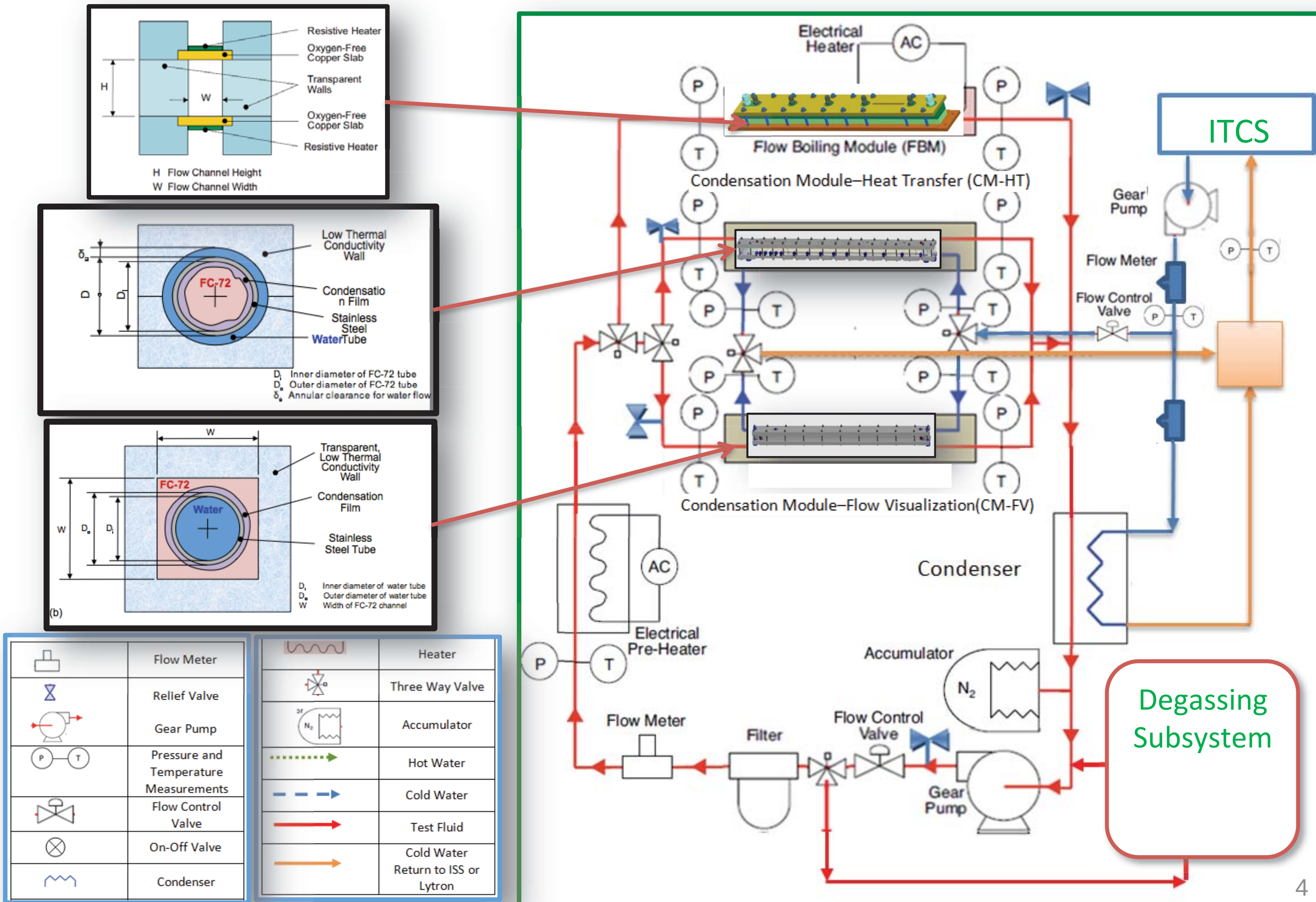


Interfacial Lift-off Model: (a) schematic representation of wavy vapor layer. (b) Balance of vapor momentum and interfacial pressure difference at moment of wetting front separation.



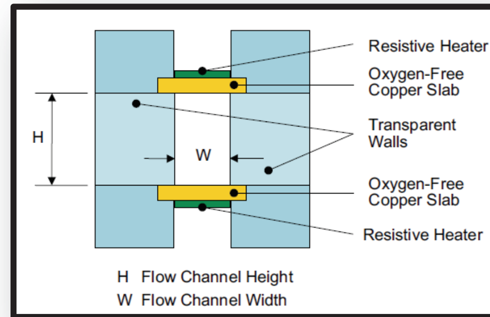
•Science Requirements Document for FBCE, March, 2013
•Science Concept Review Presentation, December 2011

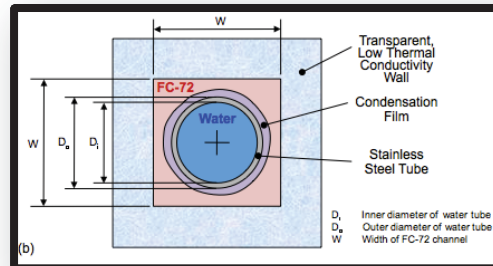
Preliminary Engineering Fluid System Design (ISS)

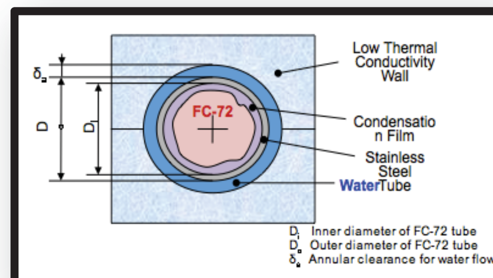


Test Modules

- Flow Boiling Module
  - Subcooled, saturated and 2-phase Inlet condition at:
    - 2.5 < Mass Flow Rate < 40 g/s
    - Heat Flux < 60 W/cm^2
- Condensation Module –Flow Visualization
  - Saturated vapor Inlet condition
    - 2 < Mass Flow Rate < 14 g/s
- Condensation Module –Heat Transfer
  - Saturated vapor Inlet condition
    - 2 < Mass Flow Rate < 14 g/s



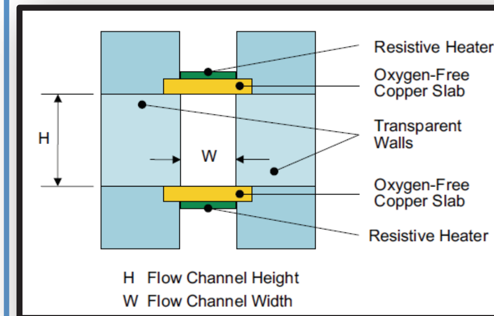


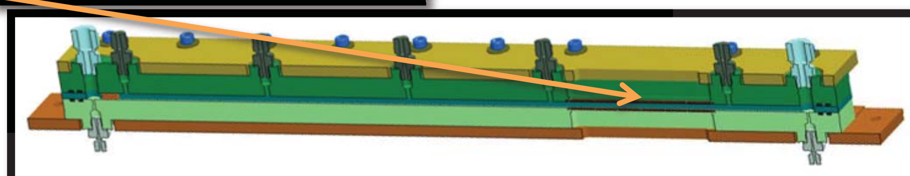


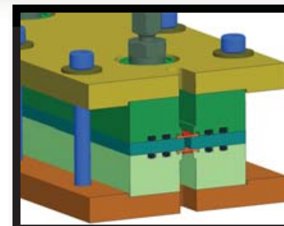
•Science Requirements Document for FBCE, March, 2013
•Science Concept Review Presentation, December 2011

Flow Boiling Module Design

- FBM/Heater Design
  - Flow Channel 2.5x5x100 mm
  - Both surfaces are heated with resistive heaters
  - Max heating of 300 W from both sides
  - Visualization with high speed camera 2000-4000 fps

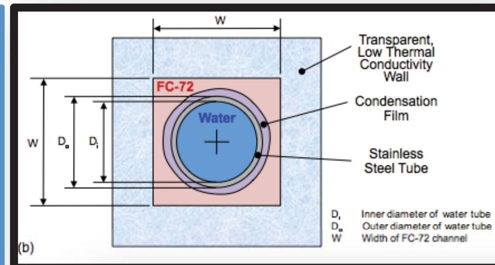


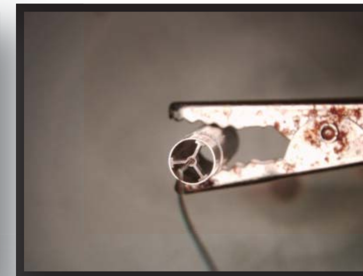


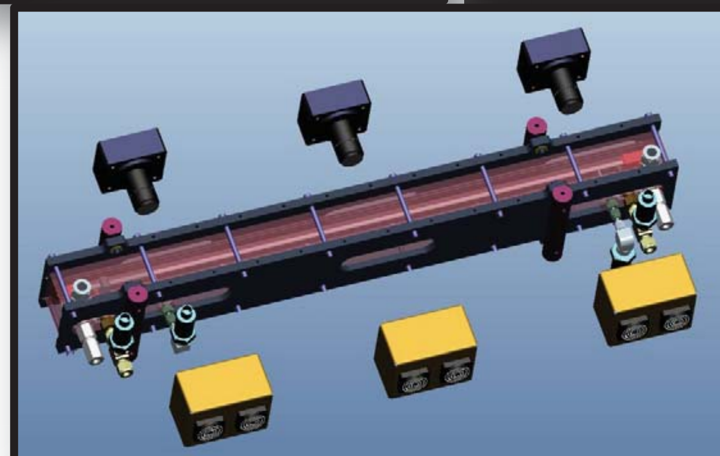


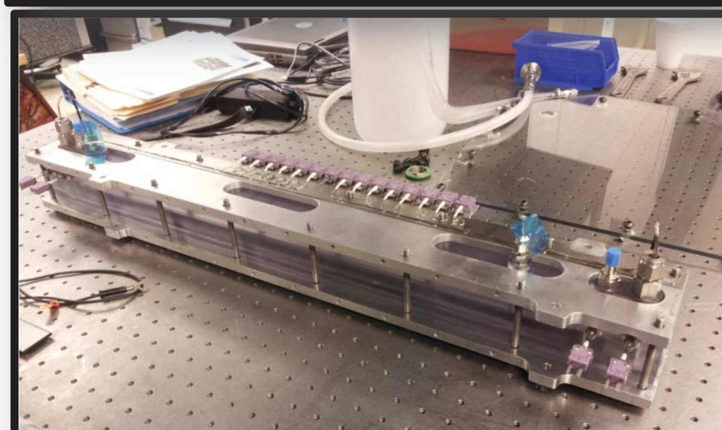
CM-FV Design and Challenges

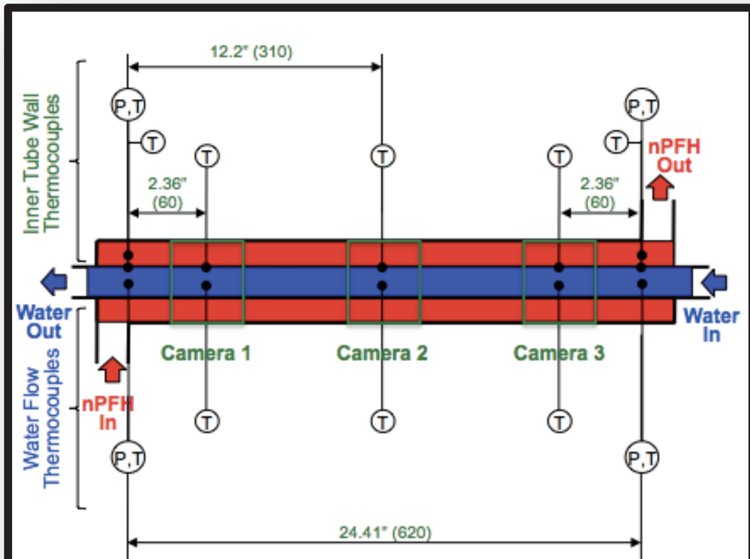
- Science requirements called for TCs on the inner surface of water tube and middle of tube
- Sectional tube design
- Three observation areas coincident with data collection areas
- Easy Access to inner tube







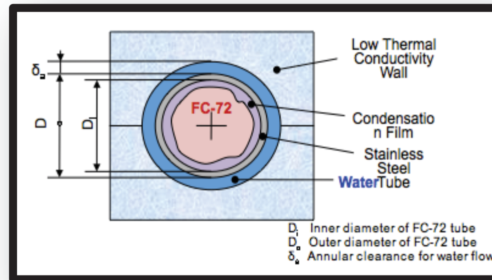


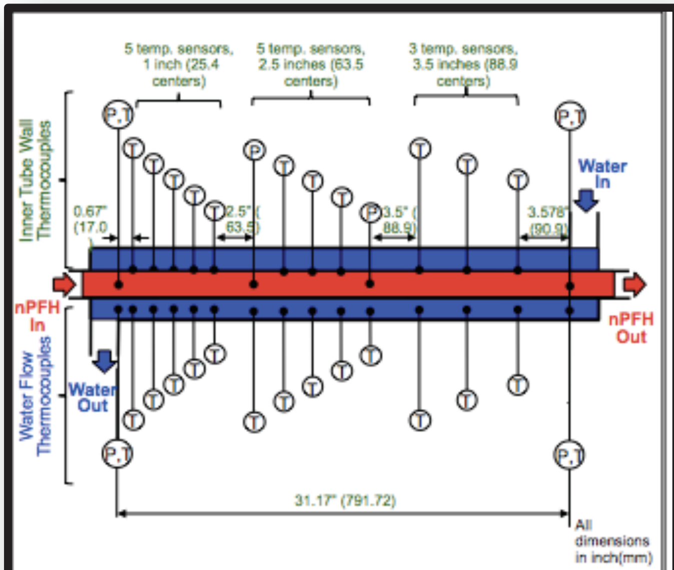


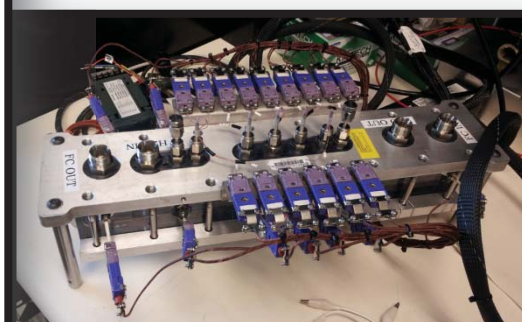
Counterflow of water loop (blue) and FC-72 (red, nPFH for flight) along with thermocouples (T) and pressure transducers (P) location

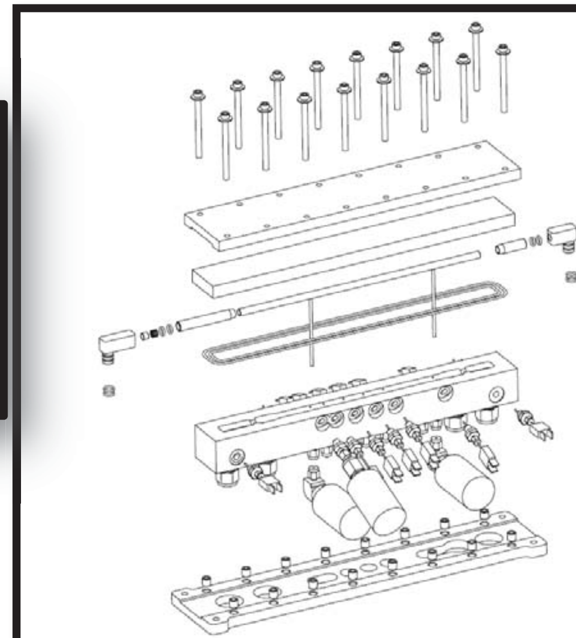
CM-HT Design and Challenges

- CM-HT Short Design
  - Easy access to inner tube
  - TCs are fixed firmly to outer surface of inner tube
  - Eng. Model CM-HT is a longer version of CM-HT Short







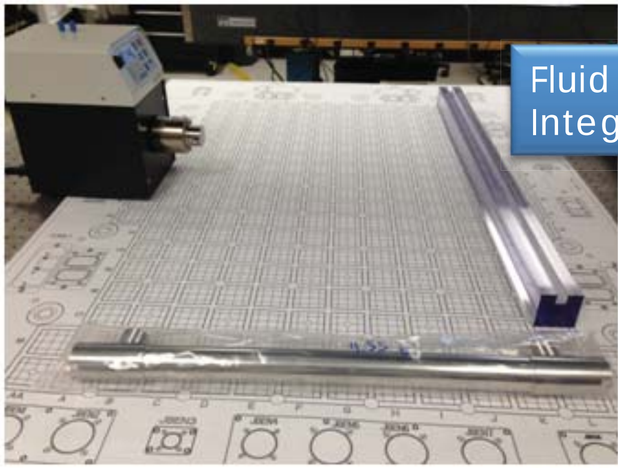


Counterflow of water loop (blue) and FC-72 (red, nPFH for flight) along with thermocouples (T) and pressure transducers (P) location

Ground Testing

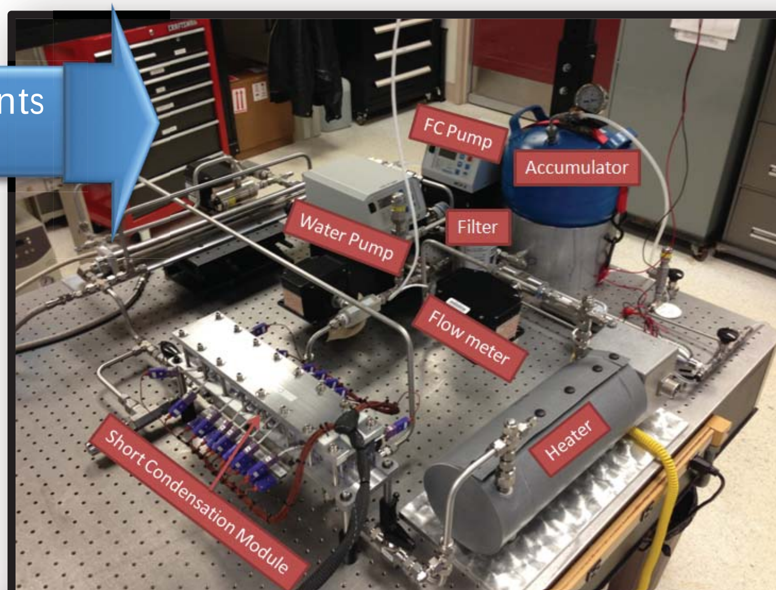
- Breadboard Development
- Pre-heater Characterization
  - Operation
  - Control
- Testing of potential design for On-Orbit degassing

Ground Testing-Breadboard Development

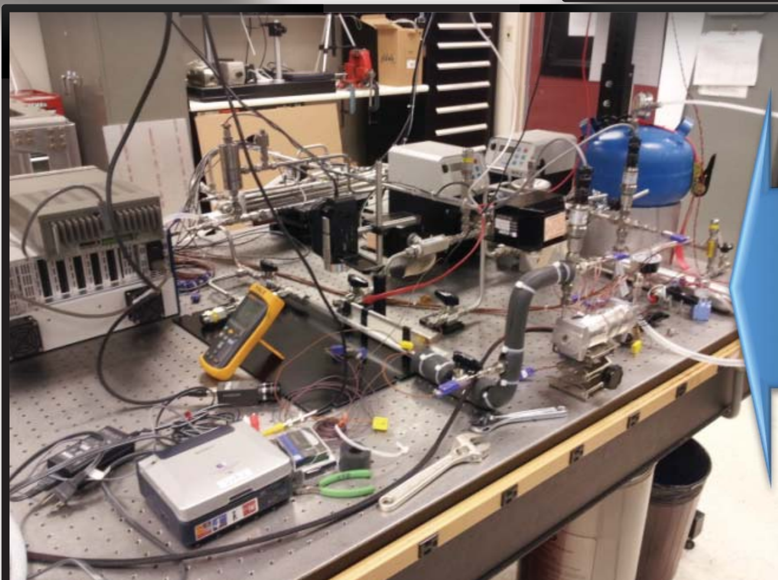


FIR layout on optical bench with pump, CM-FV vapor and collinear flow tube

Fluid System components Integrated

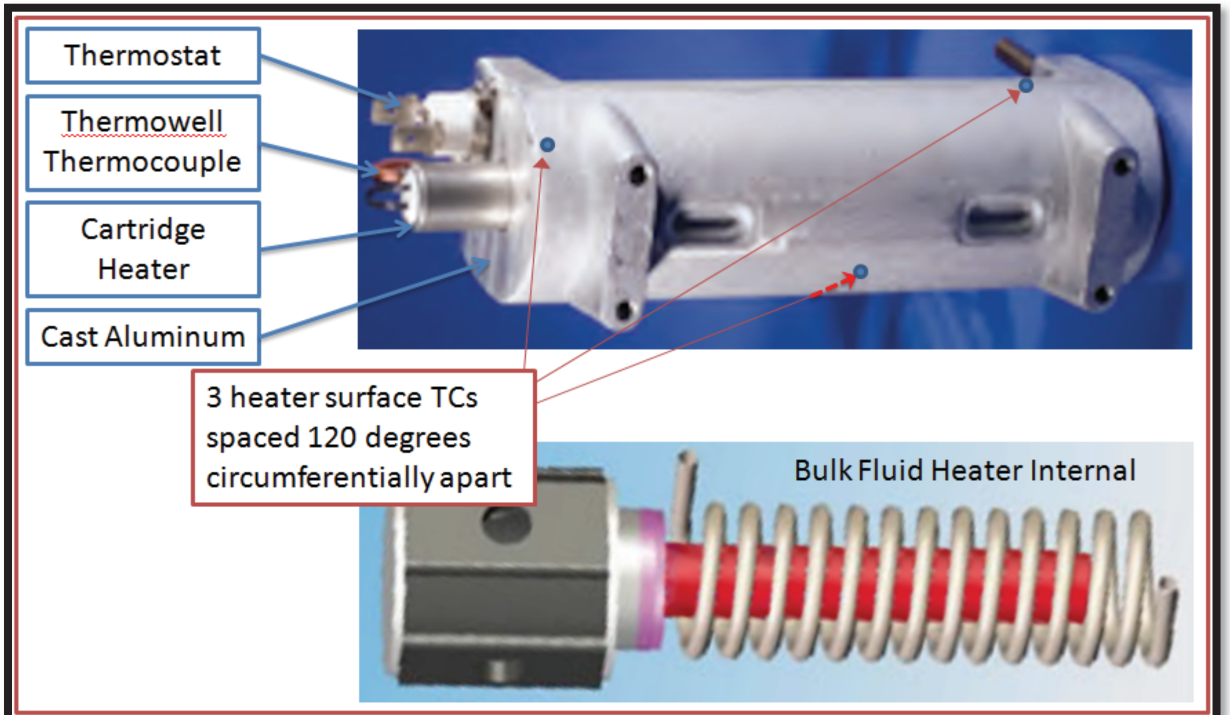


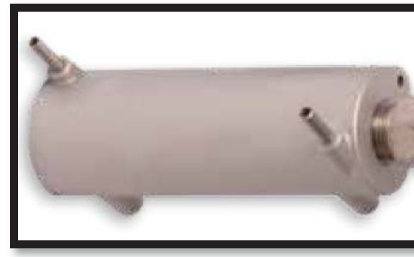
Fluid System components Integrated with instrumentations for heater evaluation



Ground Testing-Pre-Heater Characterization

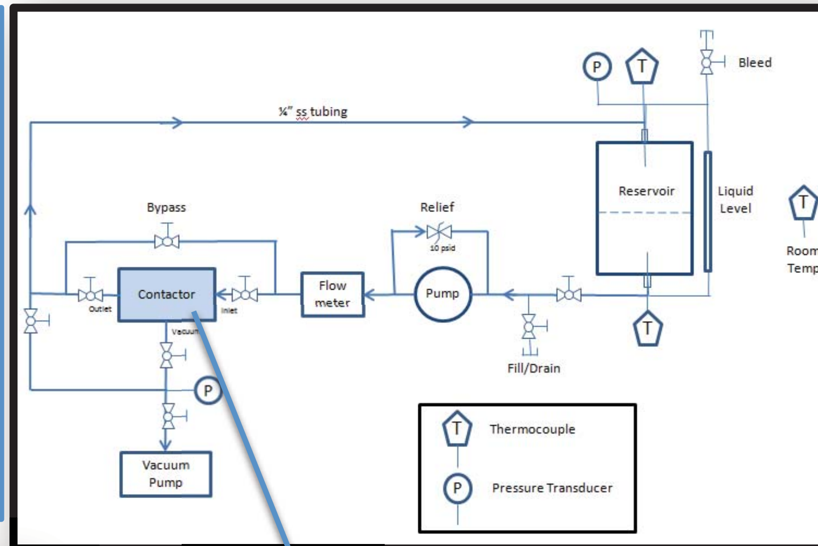
- Pre-heater studies of time constant to achieve steady state
- Steady state achieved within 6 minutes

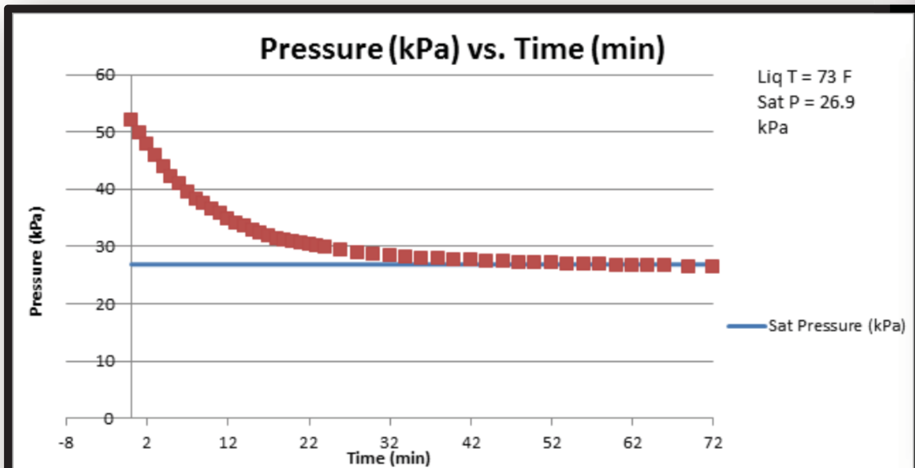


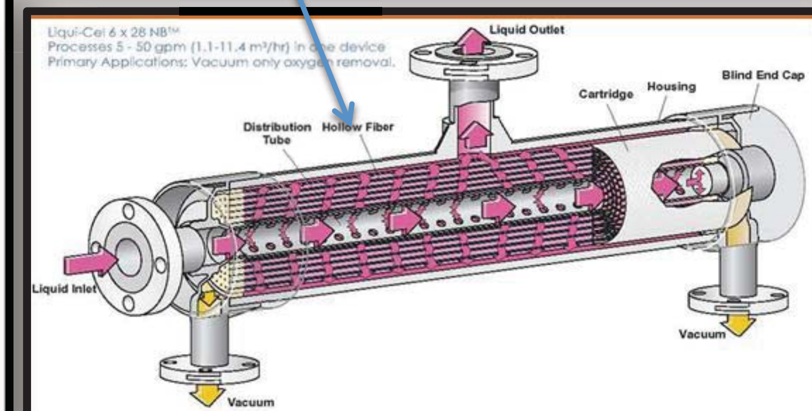


Ground Testing of Proposed On-Orbit Degassing System

- Developed a fluid loop for degassing testing
- Use of membrane contactor
- Testing showed after 50 minutes, partial pressure of non-condensable gases is below 2 kPa



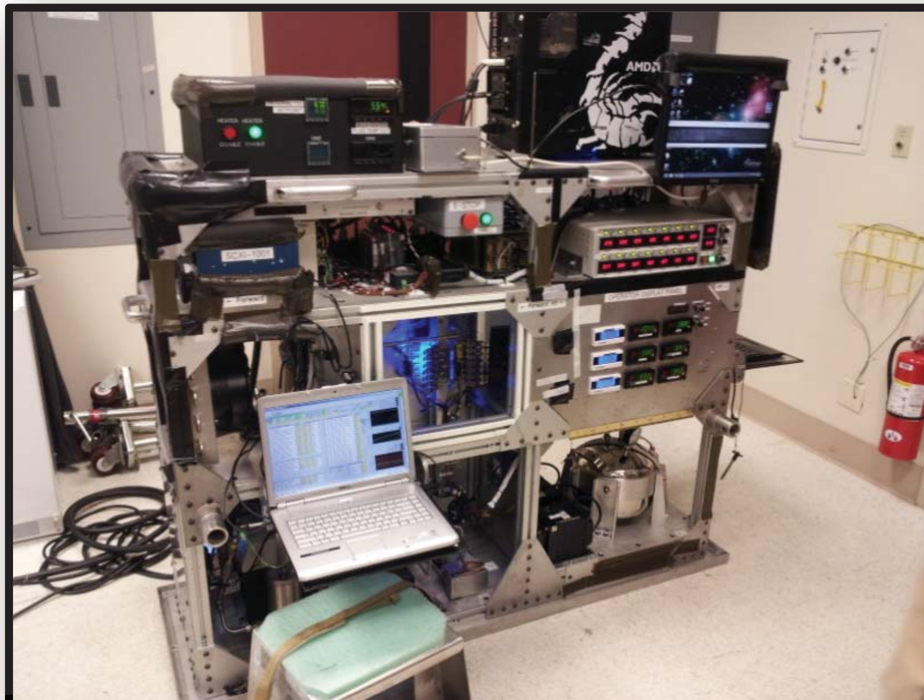


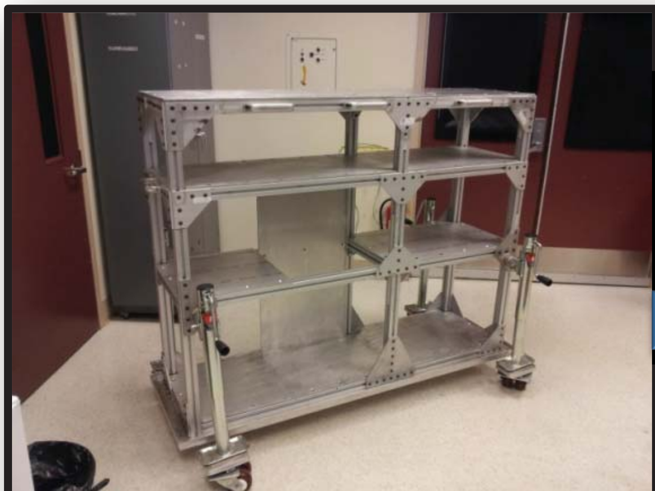


Zero-G Aircraft Testing/FBM Engineering Assessment

Aircraft Rack Features:

- Fluid System
- Diagnostics:
  - Lumenera and Sentech video cameras
- FBM Heater Power Input and Temperature Control
- Data acquisition



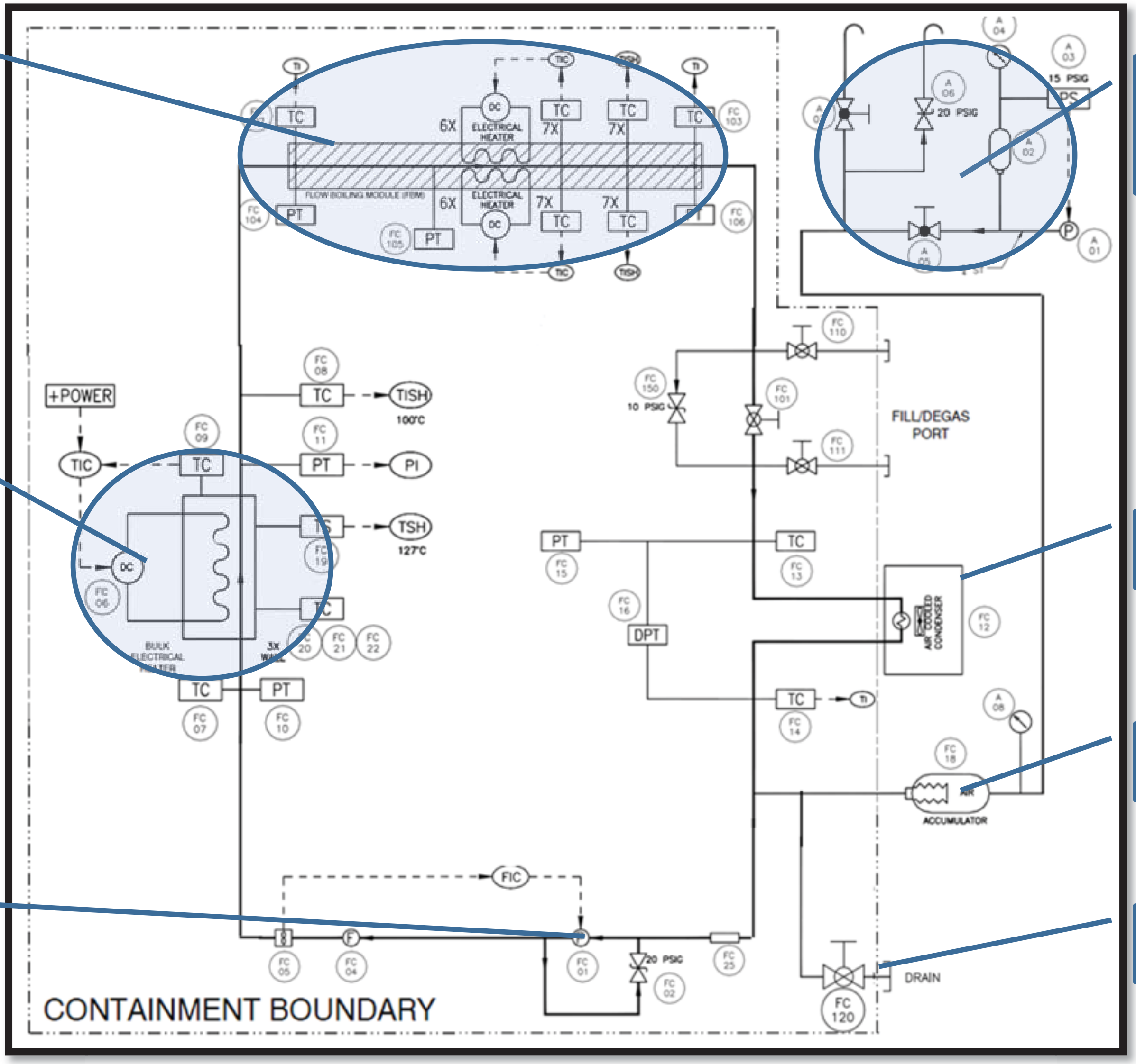


Fluid System

FBM

Heater

Pump



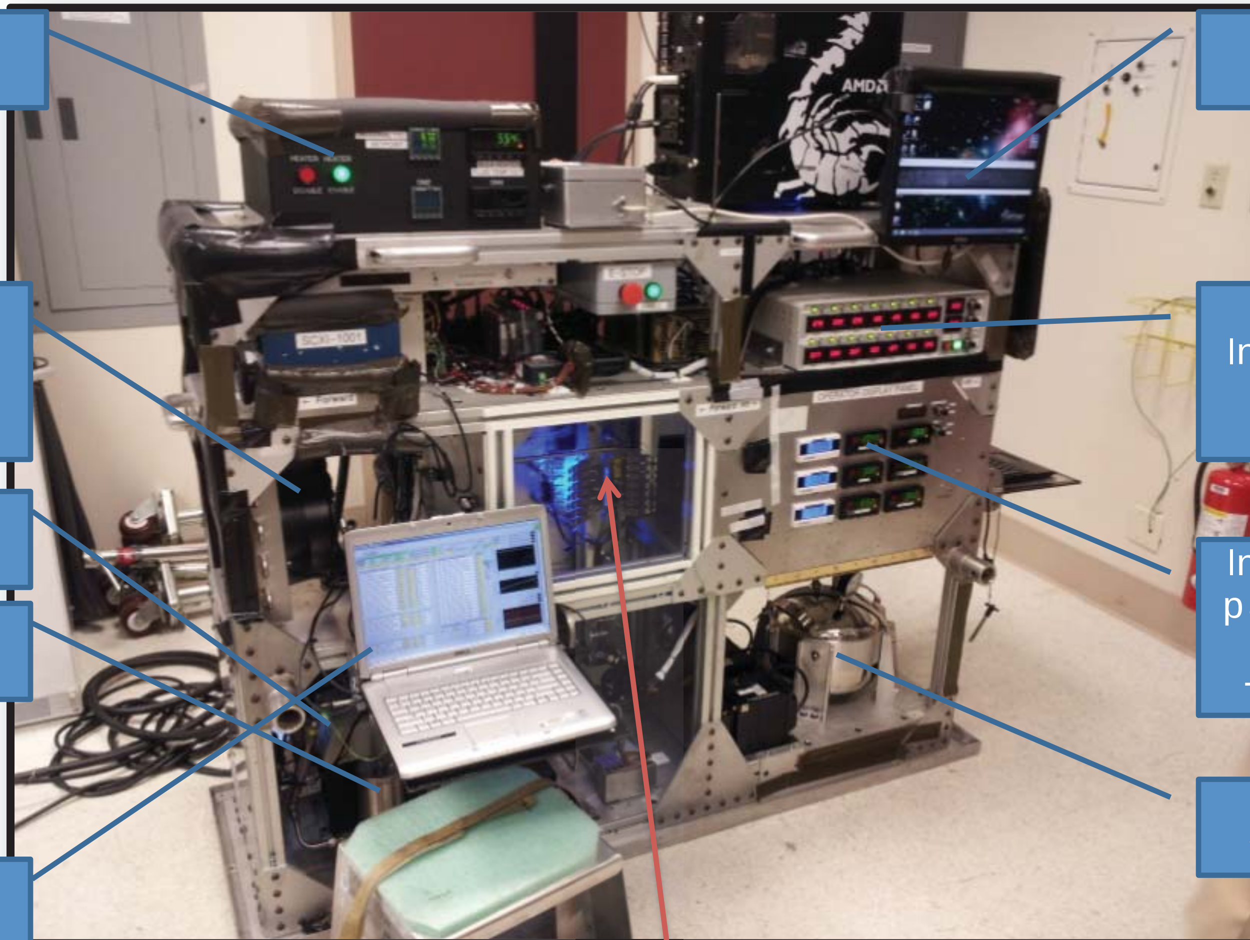
Accumulator Pressure Control

Condenser

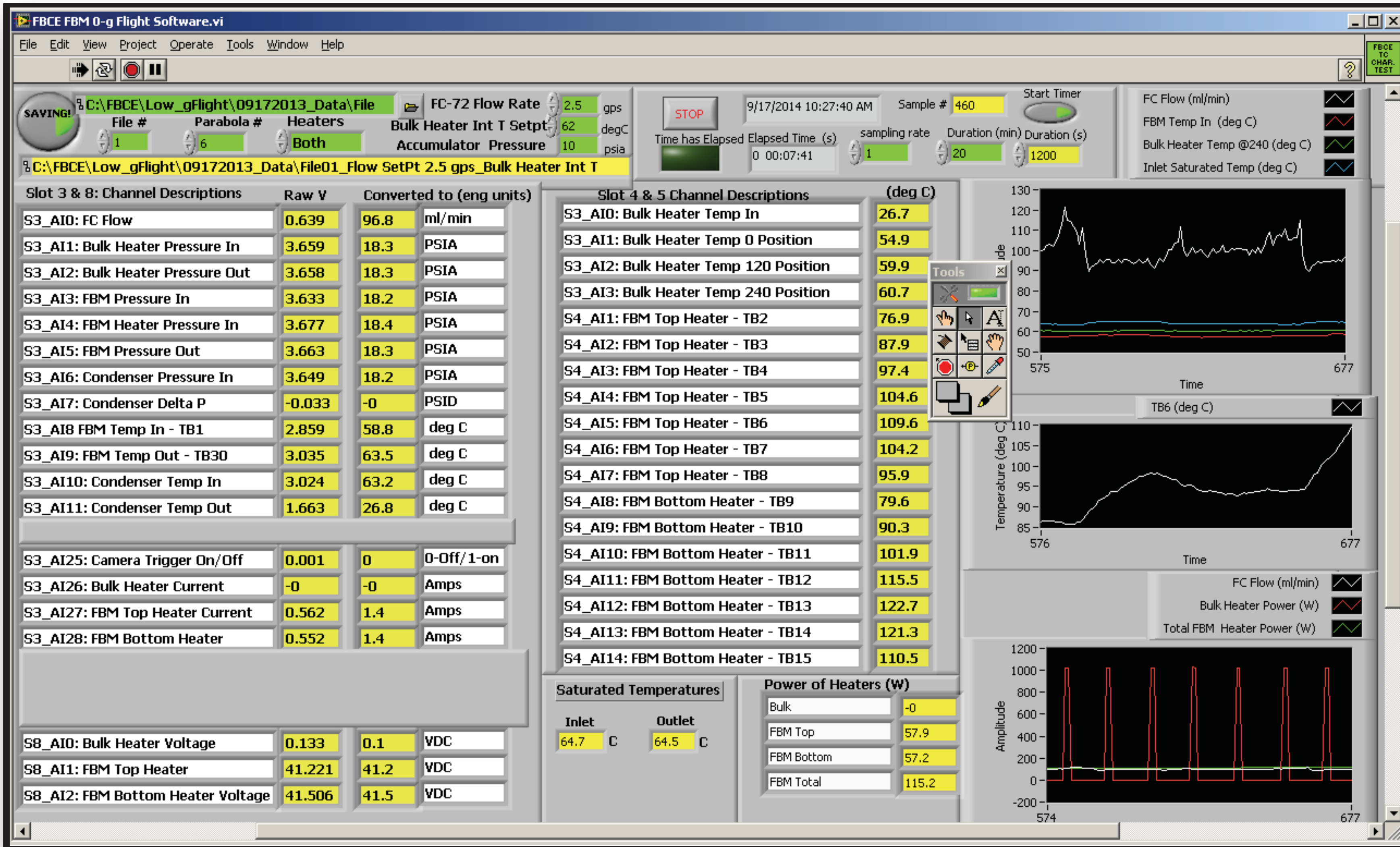
Accumulator

Drain

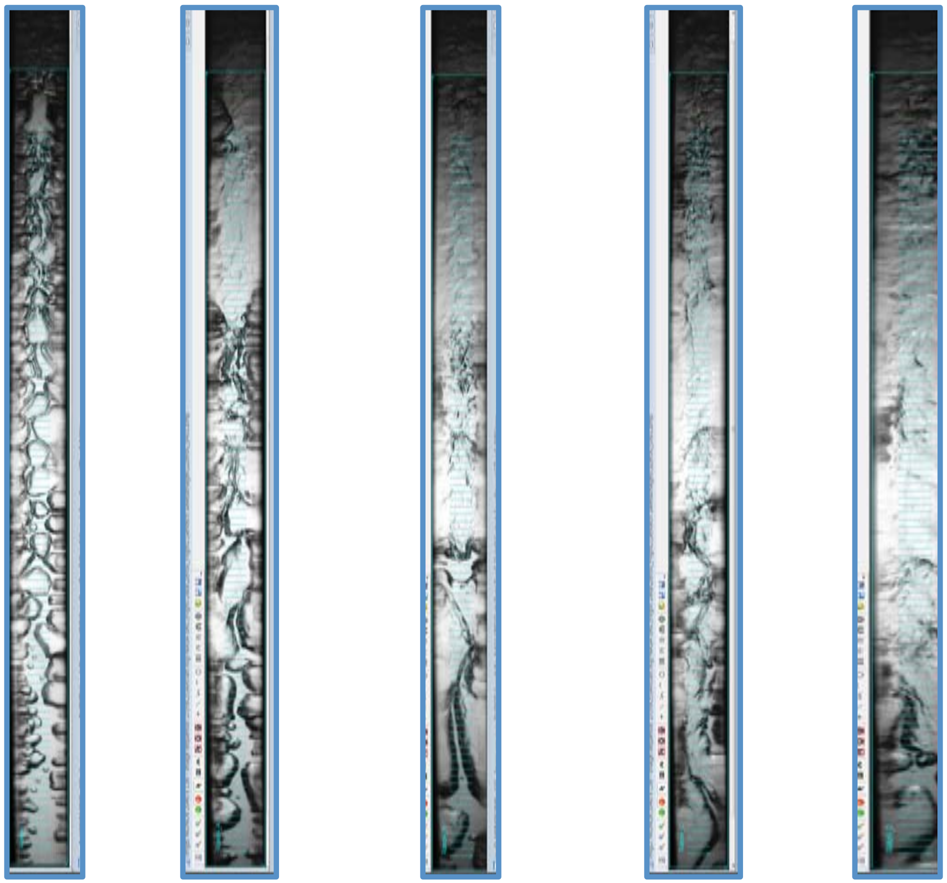
Zero-G Aircraft Rack

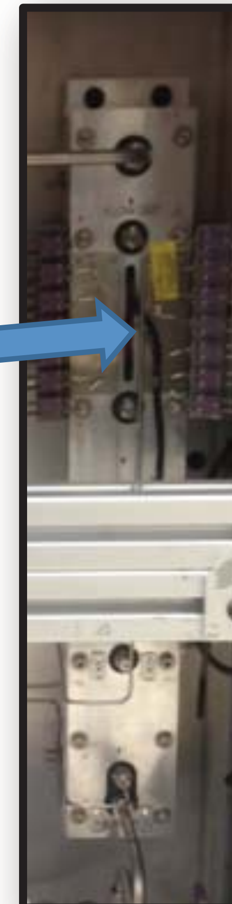


Data Acquisition- $\dot{m} = 2.5\ g/s$



Testing Results-High Speed Visualization- $\dot{m} = 2.5\ g/s$

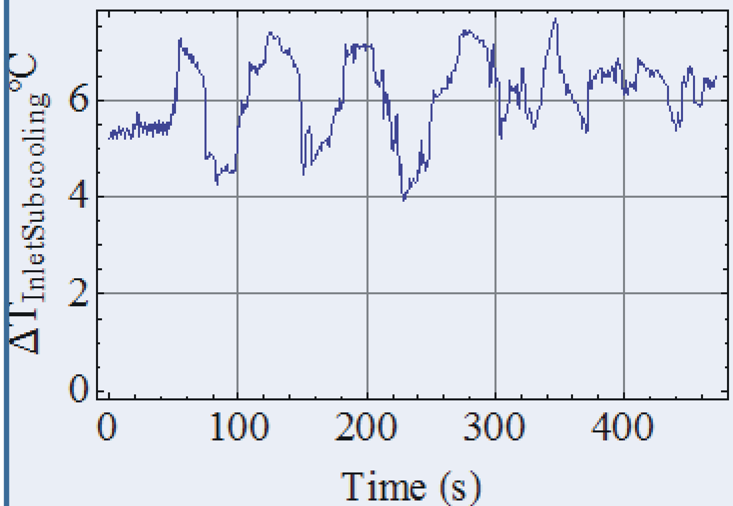




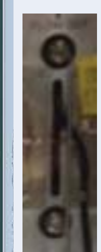
36% 57% 79% 92% 100%

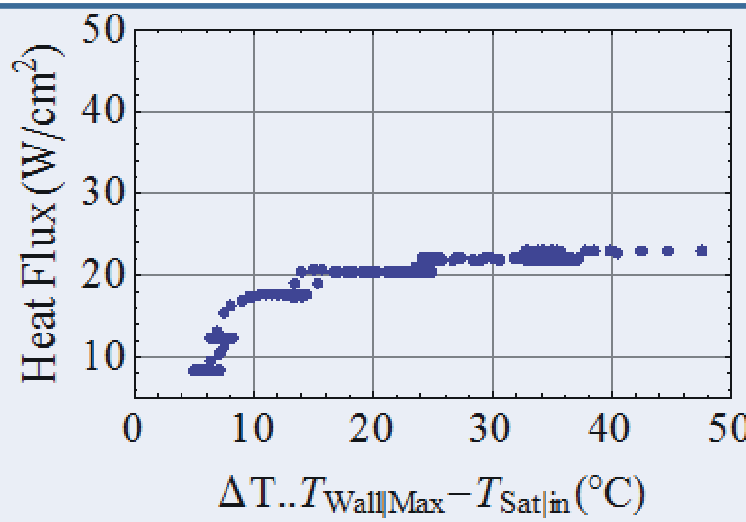
% of CHF achieved in each of the 5 low gravity paraboli performed at 2.5 g/s

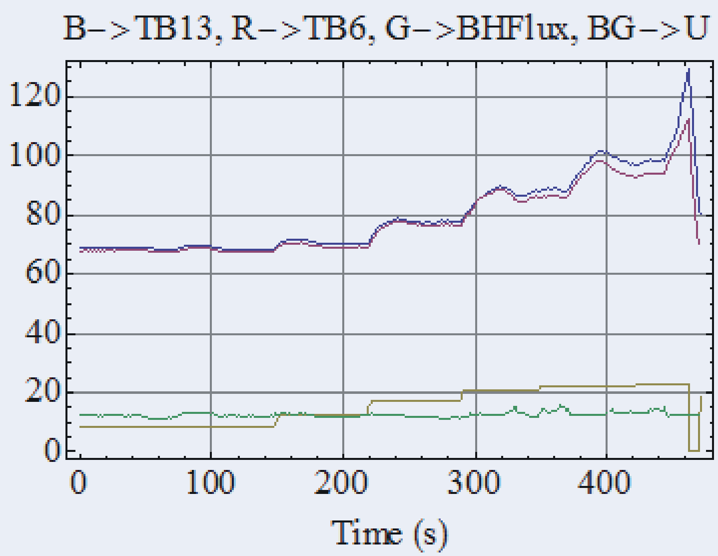
Testing Results-$\dot{m} = 2.5\ g/s$, 2 Heaters

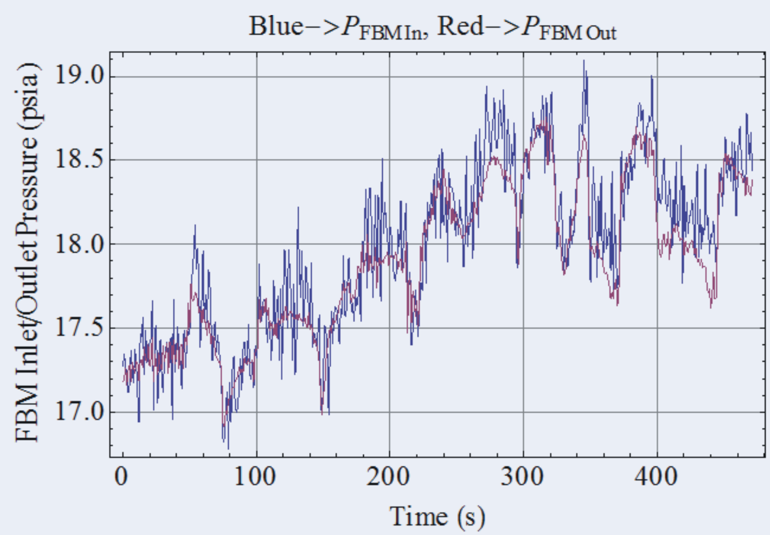


FC Out



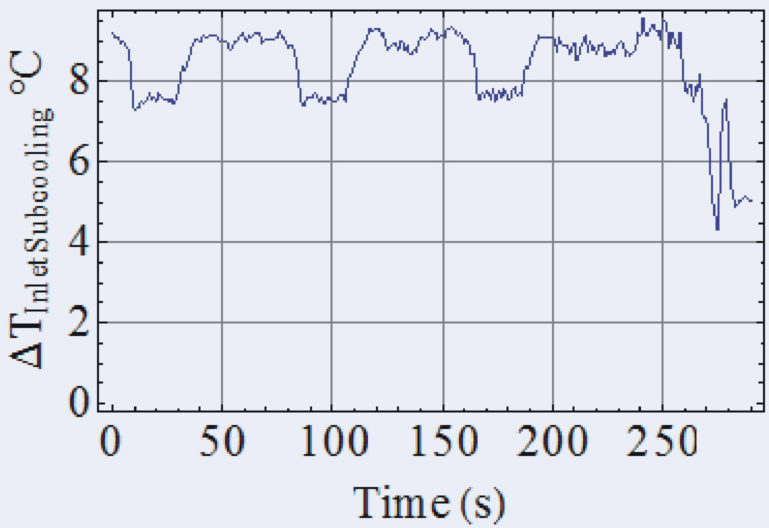


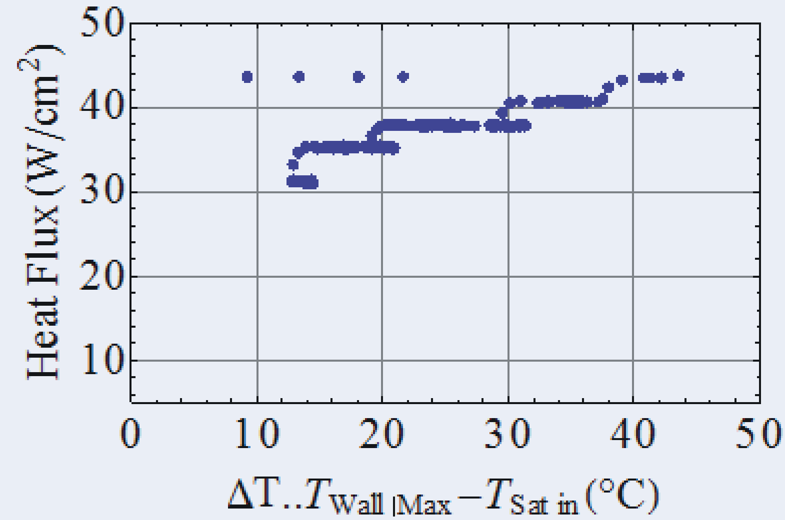


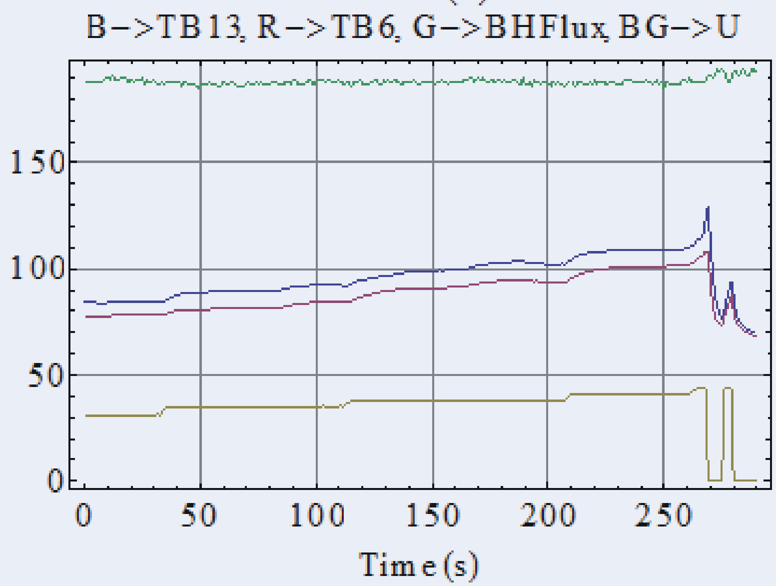


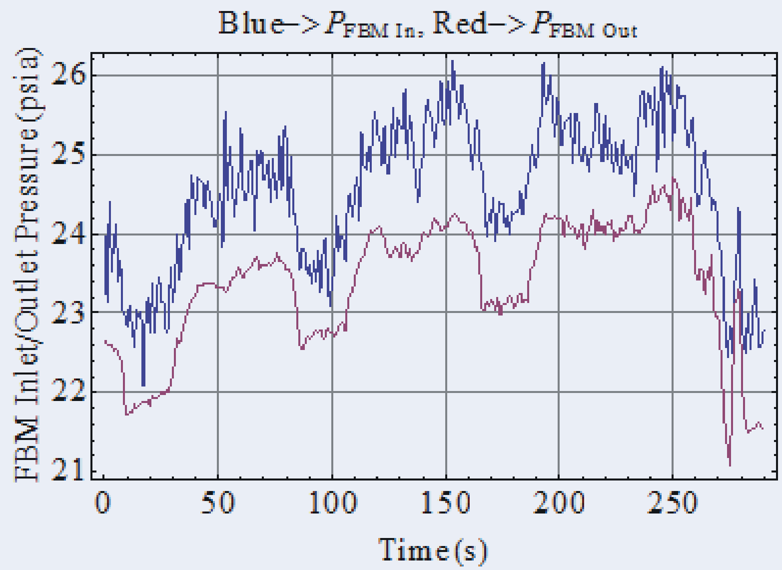
FC In

Testing Results- $\dot{m} = 40\ g/s$, 2 Heaters









Future Plans

- Ground and Low gravity testing of condensation modules
- Development of engineering model prior to or by PDR planned for January 2015

- Thank you
- Questions?